Global Scenarios for Biofuels: Impacts and Implications

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Abstract

In recent years, bioenergy has drawn attention as a sustainable energy source that may help cope with rising energy prices, but also maybe provide income to poor farmers and rural communities around the globe. Rising fuel prices, growing energy demand, concerns over global warming from GHG emissions and increased openness to renewable energy resources, domestic energy security, and the push for expansion into new markets for crops in the face of world trade outlooks are all factors driving interest in expanding bioenergy use. Despite keen interest in this sector, there are currently few players in this field: In 2005, Brazil and the United States together accounted for 99 percent of global ethanol production, whereas Germany and France accounted for 69 percent of global biodiesel production. However, developing countries with tropical climates may have a comparative advantage in growing energy-rich biomass; and second-generation technologies could enable expansion of the range of feedstock used from the traditional sugarcane, maize, and rapeseed to grasses and trees that can thrive in less fertile and more drought-prone regions. Potentially adverse impacts from a rapid bioenergy expansion include upward pressure on international food prices, making staple crops less affordable for poor consumers; potentially significant adverse impacts on both land (soil quality and fertility) and water resources; and on biodiversity and ecosystems, in general.

Given the numerous and high level of uncertainties regarding future biofuel supply, demand, and technologies, the paper examines three alternative scenarios: a conventional scenario, which focuses on rapid global growth in biofuel production under conventional conversion technologies; a second generation scenario, which incorporates a 'softening' of demand on food crops due to 2nd generation, ligno-cellulosic technologies coming online; and a 'second generation plus scenario', which adds crop productivity improvements to the second generation scenario, which essentially further reduce potentially adverse impacts from expansion of biofuels.

Results from the analysis show a potential food and water-versus-fuel tradeoff if innovations and technology investments in crop productivity are slow, and if reliance is placed solely on conventional feedstock conversion technologies to meet future blending requirements of fossil fuels with biofuels. This situation changes considerably with increased investments in biofuel conversion and crop productivity improvements. To mitigate potentially adverse impacts from aggressive increases in biofuel production therefore requires a renewed focus of crop breeding for productivity improvement in wheat, maize and even sugar crops. While some crops may be more favorable from the perspective of profitability, they may encounter binding environmental constraints, in particular water, for example, for sugarcane in India, and wheat or maize in Northern China. And even where water might be available, other natural resource constraints, such as land availability can constrain expansion, such as in Southern China.

Impacts of global biofuel development and growth on rural poor can be both positive and negative. Biofuel crops do not necessarily crowd out food crops, at least not under the alternative scenarios examined here. Instead there is room for complementarities and synergy and rural agricultural development and socioeconomic growth can go hand-in-hand with enhancement of bioenergy production capacity.

We can get fuel from fruit, from that shrub by the roadside, or from apples, weeds, saw-dust—almost anything! There is fuel in every bit of vegetable matter that can be fermented. There is enough alcohol in one year's yield of a hectare of potatoes to drive the machinery necessary to cultivate the field for a hundred years. And it remains for someone to find out how this fuel can be produced commercially—better fuel at a cheaper price than we know now.

~ Henry Ford, 1925

1. Introduction

Rising world fuel prices, the growing demand for energy, and concerns about global warming are the key factors driving renewed interest in renewable energy sources and in bioenergy, in particular. Henry Ford's seemingly prescient outlook is thus becoming much more relevant 80 years on. Within a global context, fossil fuel consumption still dominates the world energy market (Figure 1). However, the uncertainty in future supply, potentially unsustainable patterns of energy consumption, and the costs of expanding proven reserves of fossil fuels have lead many energy analysts and managers around the world to seek alternatives from other, more renewable resources, such as bioenergy. The steadily increasing trend of gasoline prices over time (Figure 2) strengthens the rationale for seeking cheaper supply alternatives. Biofuels already constitute the major source of energy for over half of the world's population, accounting for more than 90% of the energy consumption in poor developing countries (FAO 2005a). Besides alleviating the reliance of energy-driven economies on limited fossil fuel sources, bioenergy has continued to receive increasing attention from those concerned with promoting agricultural and environmental sustainability through the reduction of carbon emissions, an important component of climate change mitigation. Bioenergy is also considered by some to be a potentially significant contributor towards the economic development of rural areas, and a means of reducing poverty through the creation of employment and incomes – linking biofuel development directly or indirectly with multiple Millennium Development Goals (FAO 2005b; Kammen 2006). Thus, bioenergy is seen, more and more, as a promising and largely untapped renewable energy resource, and its potential environmental and economic benefits are becoming more apparent as technological improvements continue to emerge.

Large amount of biomass from forest and agricultural activities such as branches, tree tops, straw, corn stover and bagasse from sugarcane can be utilized as feedstock for bioenergy. Likewise, bioethanol and biodiesel can be produced from sugar, grain, and other oil crops. In parts of the world, animal dung is processed as fuel while effluents are digested to produce biogas (IEA Bioenergy 2005). Table 1 shows typical types of biofuel generated together with the energy services they supply using a number of biomass resources.

The development of commercial bioenergy production dates back to the use of maize for ethanol, and has seen consistent growth in a few countries. Ethanol is produced from maize in the United States, India, and China, for example. Moreover, in Brazil 50% of all sugarcane produced out of 357.5 million tons in 2003-2004 was devoted to ethanol (Szwarc 2004). Globally, bioethanol production is concentrated in two countries, Brazil and the United States (Table 2).

Biodiesel production, on the other hand, is geographically concentrated in the EU – with Germany and France leading production (Table 3). The production processes used to manufacture biodiesel from its feedstock sources differs from that used for bioethanol, as it relies on trans-esterification of oils, whereas bioethanol production relies on the hydrolysis of the constituent grains and sugars of plants into ethanol, under conventional technologies (Worldwatch 2006).

Despite the apparent success of bioenergy production in these countries, other countries have been reluctant to take a more aggressive approach towards bioenergy development, due to the existence of institutional, financial or political constraints. Several factors could contribute towards this hesitancy to adopt these technologies, including a) a lack of understanding, among policymakers, of the potential benefits; b) the neglect of biofuel within the national political, economic, and social agendas, thereby preventing its integration into energy statistics and national energy planning; c) the prevailing regulatory, institutional and legal restrictions that discourage the development of biomass energy; d) the inattention of forestry and agricultural agencies towards the development, management and use of biomass energy resources; and e) the lack of policy attention paid to the introduction and distribution of modern, efficient and clean bioenergy production system (FAO 2003).

Some policymakers have also voiced concerns that aggressive growth in bioenergy production could "crowd out" the production of food crops in some developing countries that try to adopt it, in order to substitute for the import of expensive fossil fuels (Graham-Harrison 2005).

In this paper, we investigate the interaction of biofuel demand with the demand and production of food and feed crops, to examine potential impacts on food prices and food security. The analysis does not only focus on the United States, Brazil and China – which account for the global share of energy demand increase, but takes on a global approach to future bioenergy uses. The analysis focuses on biofuel use in the transportation sector.

2. Scenario analysis

Over the next several decades, the most certain increase in demand for biofuels is going to focus on displacing liquid fuels for transport, mostly in the form of ethanol which currently supplies over 95% of the biofuels for transportation (Fulton et al. 2004). At present, the most efficient production of ethanol is based on dedicated energy crops, such as sugarcane and maize. At the same time, these dedicated ethanol crops will likely have the greatest impact on food supply and demand systems. This is particularly true if the production occurs on prime agricultural lands as is likely given the need to reduce transportation costs of both the feedstocks and fuel products to and from larger, centralized ethanol production facilities.

The projected demand for transportation fuel is shown in Figure 3, where we see very high and rapidly increasing demand for countries like China. These estimates are based on projections of energy demand obtained from the energy outlooks given by the International Energy Association (2004) as well as outlooks given in the agricultural baseline projections of USDA (2006).

On the basis of these projected demands, we estimate fossil-based fuel displacement (with biofuels), in order to obtain projections of biofuels used for transportation uses (Figure 4). The expected rate of blending or displacement of fossil-based fuels with biofuels was obtained (for major biofuel-producing countries) from projections by the International Energy Association (IEA) Bioenergy Task 40 group, for Brazil to 2010 and 2015, and by the targets for biofuel production currently being considered in China (Liu 2006). We also use the USDA's Agricultural Baseline projections for fuel alcohol use from maize in the USA (USDA 2006) in our model quantification. For those countries with no published data on future fuel displacement, we assumed a rate of displacement that corresponds to 10 percent displacement by 2010, 15 percent by 2015 and 20 percent by 2020. This constitutes a fairly aggressive rate of biofuel production growth, but allows us to see the 'upper bound' impacts that would occur if biofuel adoption were to be undertaken in earnest, in response to global energy price trends. No growth in biodiesel production was assumed outside of the European Union, since those countries currently dominate global production (Table 3), and do so with the help of agricultural support policies that would be hard for other emerging producers to follow suit and adopt in a likewise fashion.

In order to examine the potential impact of biofuel production growth on country-level and domestic agricultural markets, we use a partial-equilibrium modeling framework that can capture the interactions between agricultural commodity supply and demand, as well as trade, at the global level. In doing so, we are able to simulate the resulting growth in demand for the agricultural crop feedstocks that biofuel production relies on, while also tracking the demand for food and feed for those same agricultural crops.

The model used for this analysis is the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT), which has been used by the International Food Policy Research Institute (IFPRI) for projecting global food supply, food demand and food security to 2020 and beyond (Rosegrant et al. 2001). The model contains three categories of commodity demand – food, feed and other use demand. The 'other use' demand category is expanded in this study to reflect the utilization of a particular commodity as biofuel feedstock. The utilization level is determined by the projected level of biofuel production for the particular commodity in question. By converting the target levels of ethanol production into the necessary tonnage of maize, sugarcane or other crop feedstock, we can shift the levels of 'other demand' appropriately to reflect the increased utilization of these commodities as biofuel feedstock. The conversion rates used are 400 liters of ethanol for every ton of maize, and 80 liters of ethanol for every ton of sugarcane. These rates are in line with a variety of sources, including Bullock (2002), Durante and Miltenberg (2004), Fulton et al. (2004), Giampietro and Ulgiati (2005), Moriera (2000), and Walter et al. (2006).

Drawing on projections for biofuel demand for the relevant countries and regions, we construct three alternative scenarios:

1. ***Conventional scenario*** (aggressive biofuel growth with no crop productivity change). This scenario assumes very rapid growth in demand for bioethanol across all regions and for biodiesel in Europe, together with continued high oil prices, and rapid breakthroughs in biofuel technology to support expansion of supply to meet the growth in energy demand – but holding projected productivity increases for yields at baseline projection levels. The "aggressive" biofuel scenario contains the biofuel demand projections described previously, and shown in Figure 4. For bioethanol we consider maize, sugarcane, sugarbeet, and wheat as feedstock crops, whereas we consider oilseed crops and soybean for biodiesel.

2. ***2nd Generation scenario*** (or cellulosic biofuel scenario). In this scenario, second-generation cellulosic conversion technologies come on line for large-scale production by 2015. In this case, we hold the volume of biofuel feedstock demand constant starting in 2015, in order to represent the relaxation in the demand for food-based feedstock crops created by the rise of the new technologies that convert nonfood grasses and forest products. Crop productivity changes follow baseline projections.

3. ***2nd Generation Plus scenario*** (aggressive' biofuel growth scenario with productivity change and cellulosic conversion). This scenario considers, in addition to second-generation technologies, the effect of crop technology investment response that would result in increased productivity over time, in order to better support the expansion of feedstock supply in response to biofuel demand growth. Productivity improvements are in line with other projections studies relating the benefits of increased agricultural investment policies with agricultural productivity growth (see, for example, Rosegrant et al. 2005; SEARCA/IFPRI/CRESCENT 2003). The 'boost' that is given to crop productivity growth under this scenario, for the example of wheat and maize, is shown in Figure 5.

On the basis of these scenarios, we solve the model such that the commodity demands are modified to reflect the feedstock requirements for the projected bioenergy production levels in these countries after 2005. The resulting long-run market equilibria are compared to baseline model projections (without biofuels), and are reported in the next section of the paper, along with impacts on calorie availability and childhood malnutrition levels.

3. Discussion of Results and Policy Implications

The first, "conventional", aggressive biofuel growth scenario shows dramatic increases in world prices for feedstock crops by 2020 (Figure 6). The highest price impacts are seen for oil crops, as well as for sugar crops, followed by staple crops. Part of this differential is due to the relative 'thickness' of markets: markets for staple grains are larger in volume and geographic scale. The relative productivity of irrigated and rainfed grains and sugar crops, compared to mostly rainfed oilseed crops, also contributes to the relative price increases seen in Figure 6. While such a scenario would lead to large profits for bioenergy producers, who—at least in Europe—already enjoy high subsidies, food consumers would be adversely harmed. To counteract adverse impacts on biofuel companies, subsidies could be moved from farmers to industries. These kind of supports for biofuel producers already exist for many countries (e.g. within the EU), and could be in the form of tax concessions at the pump or producer credits. The high price increases for oilseed crops suggest that the relatively low-yielding oil crops will have to make up fairly high shares of total production in order to meet the oil-displacement trends embedded in the "aggressive bioenergy growth" scenario.

By contrast, the second or 2nd Generation scenario, which simulates the impact of cellulosic technologies, shows a considerable softening of upward price pressures, especially for oil crops, and underlies the potential importance of such technical innovations at the industry-level. We do not introduce improvements in conversion efficiency for non-cellulosic processes, as these technologies have been in use for some time, and show little room for improvement, based on studies cited in the literature (Worldwatch 2006).

The third scenario, finally, illustrates the importance of a crop technology innovation response at the farm production level resulting from aggressive demand for feedstock from traditional food crops. The result is a further decline in food prices. This third scenario, in particular, shows how investments within both the biofuel industry and the agricultural sector can be combined to produce more favorable outcomes, which can partially mitigate adverse consumer-level impacts.

Results for calorie availability and child malnutrition levels for the alternative scenarios are shown in Figures 7 and 8. On average, daily calorie availability in developing countries declines by 194 kilocalories per person under the conventional scenario compared to the baseline. The drop in calorie availability is strongest in Sub-Saharan Africa, at 275 kilocalories per person per day, or 11 percent compared to the baseline outcome. This level of decline is substantial given the low baseline levels in that region. Declines under the 2nd Generation and 2nd Generation Plus scenarios are much smaller, at 148 and 136 kilocalories per capita per day. Under the baseline, the number of malnourished children in developing countries declines from 163 million children in 1997 to 127 million children by 2020, with the largest declines expected for South and East Asia. Under the conventional scenario with aggressive demand for biofuel feedstock from traditional food and sugar crops, the number of malnourished children increases by 11 million children, with the largest absolute increase in Sub-Saharan Africa, followed by South Asia. In percentage terms, on the other hand, the increase is largest in Latin America (Figure 8). Impacts are considerably smaller for the other two scenarios.

Among the three scenarios examined, this scenario seems to present the most plausible outcomes of all three scenarios, as neither national governments nor fuel producers would want to engage in a large-scale expansion of production without the necessary investments being in place to ensure reliable supply of feedstock material at reasonable cost, both for producers as well as for consumers of food and feed commodities.

While we have not modeled the mechanisms by which feedstocks might be substituted in and out of biofuel production, according to their competitiveness with long-term fossil-fuel prices and each other, we have shown an illustrative set of results (for a 'fixed' menu of inputs) which argue strongly for preparatory investments in both the agricultural sector, as well as within the fuel industry itself.

4. Summary and Conclusions

In our analysis, the results show a "food-versus-fuel" and implicit "water-for-food versus water-for-fuel" tradeoff in cases where innovations and technology investments are largely absent and where policies aimed at efficiency enhancement within the sector are not undertaken. Such a bleak picture is already considerably changed when biofuel and crop production technology advancements are taken into account. While there is some uncertainty as to the timing of eventual large-scale use of cellulosic conversion technologies for biofuel production, the potential benefits to developing-country employment, and soil and water conservation are well-recognized in the literature, and make a strong case for further research in that area.

The simulations presented here suggest that the cost of biofuels could be considerably higher than the projected price of oil so there would need to be compelling non-price factors for uptake at the aggressive levels assumed, particularly in the first scenario. Indeed, there might be factors favoring the decision to adopt biofuel production that might not be captured within a strict quantitative comparison of biofuel versus fossil fuel costs, including concerns of national energy security or positive externalities to the environment. However, for developing economies to participate beneficially in the growth of renewable bioenergy production, and to also maintain adequate levels of food security, a complementary set of aggressive investments will be required. Such investments could bring about benefits for consumers of both food and energy, while also contributing to the broader growth of their economies and improved livelihoods.

While this paper does not directly address water-related implications of increased bioenergy crop production, there is no doubt that while some crops may be more favorable from the perspective of profitability, they will encounter binding environmental constraints, in particular water, for example, for sugarcane in India, and wheat or maize in Northern China. And even where water might be available, other natural resource constraints, such as land availability can constrain expansion, such as in Southern China. Both constraints will be binding in Sub-Saharan Africa, unless these crops are developed together with aggressive irrigation investment, and large-scale soil-fertility improvements, including increased levels of fertilizer applications.

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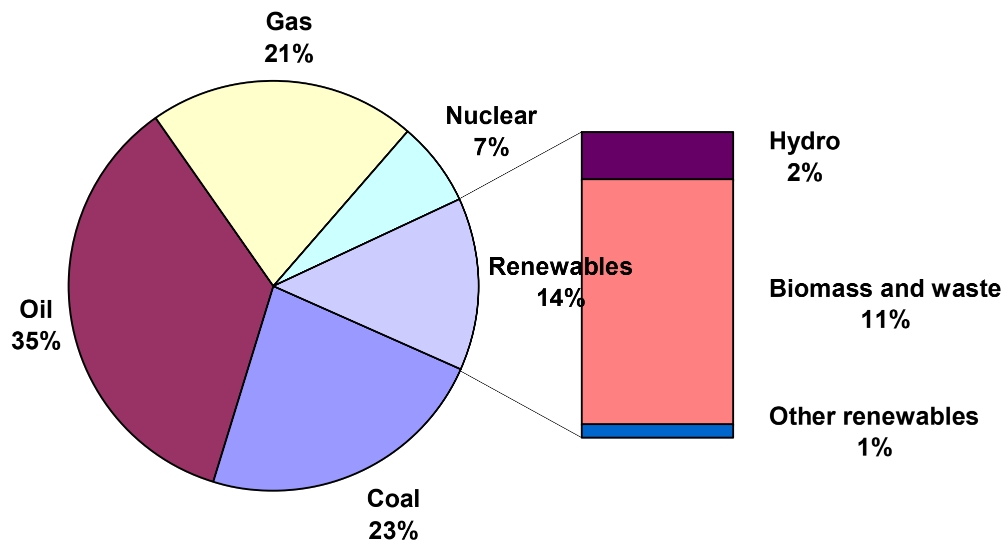
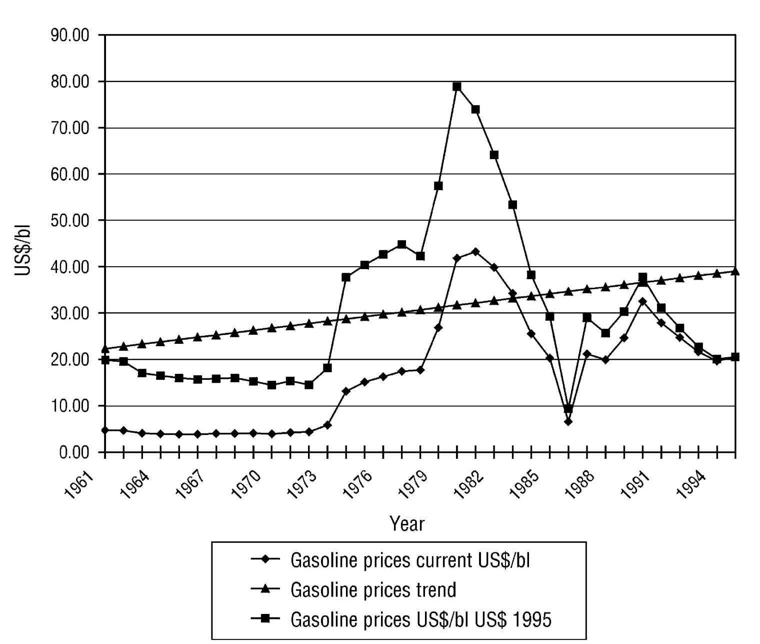
Figure 1: Share of different energy forms in global total primary energy supply at 10,345 mtoe (million tons of oil equivalent), 2002.



Source: IEA 2004

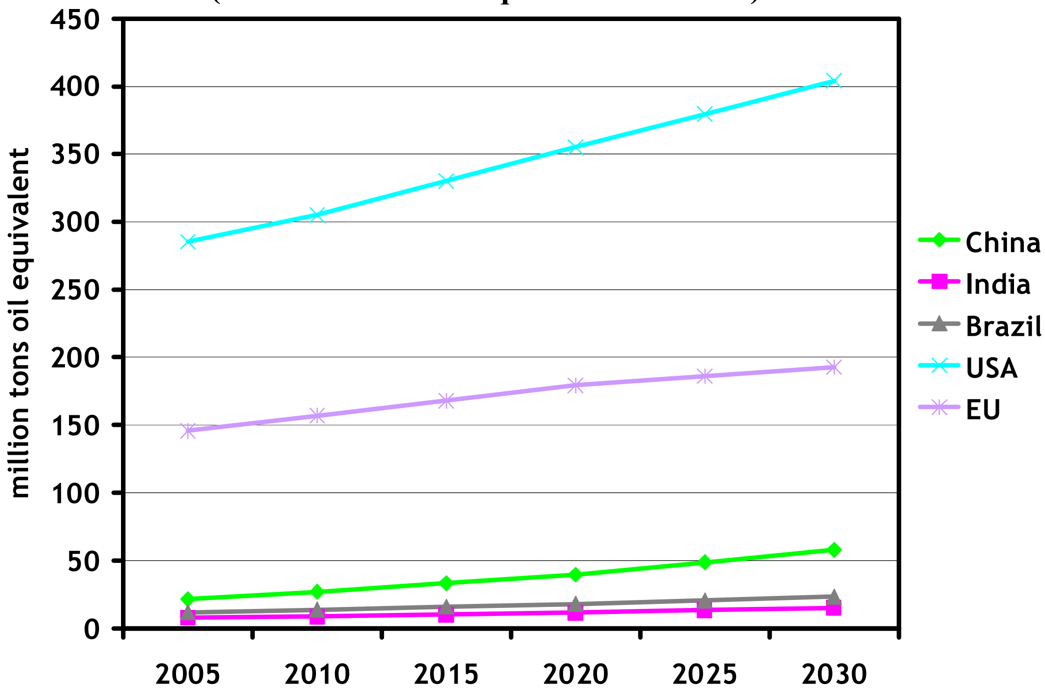
Figure 2: Gasoline prices from 1960-1996.



Source: Moreira and Goldenberg 1999

Figure 3: Projected Transportation Demand for Gasoline

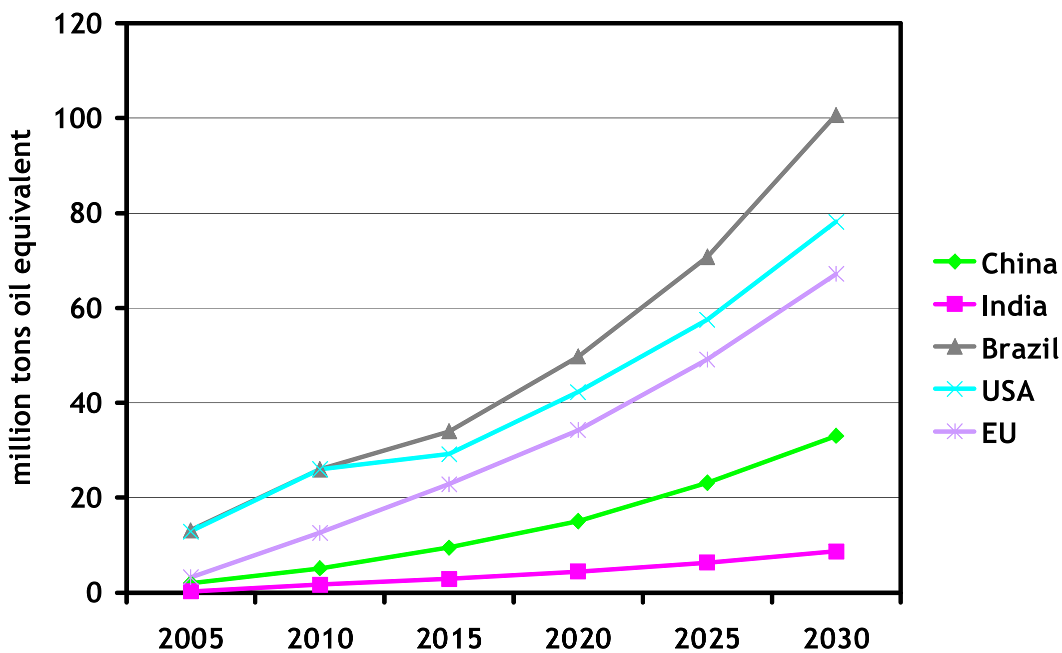
(millions of tons oil equivalent – MTOE)



Source: Author calculations.

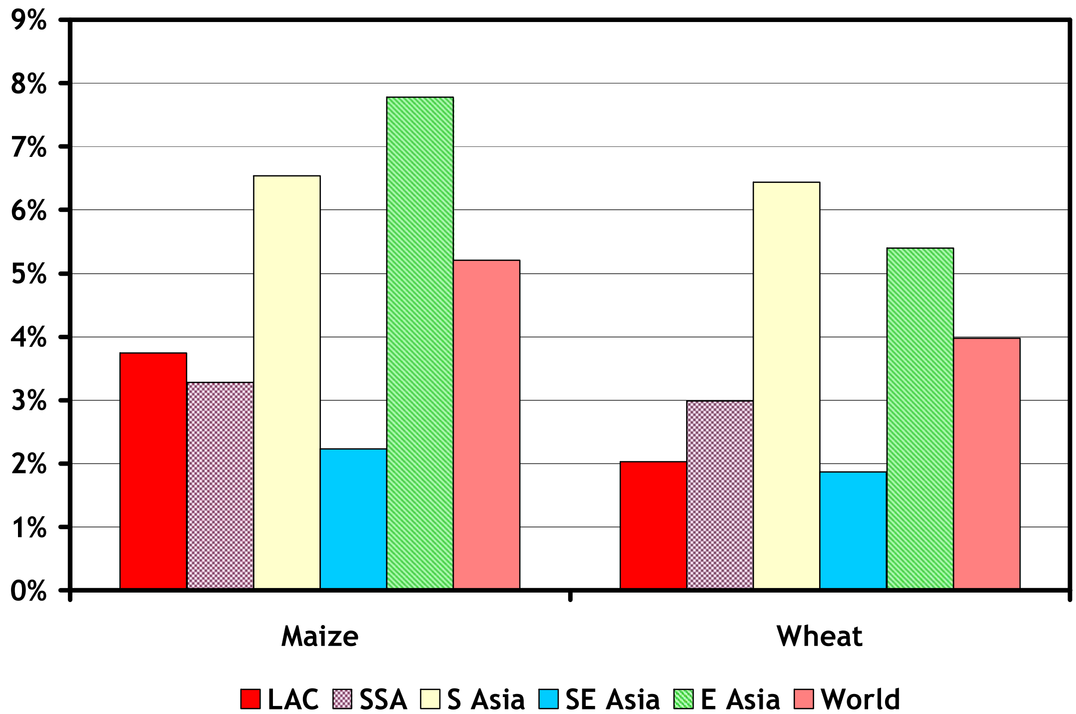
Figure 4: Simulated Total (Bioethanol + Biodiesel) Biofuel Production for Transport

(millions of tons oil equivalent)



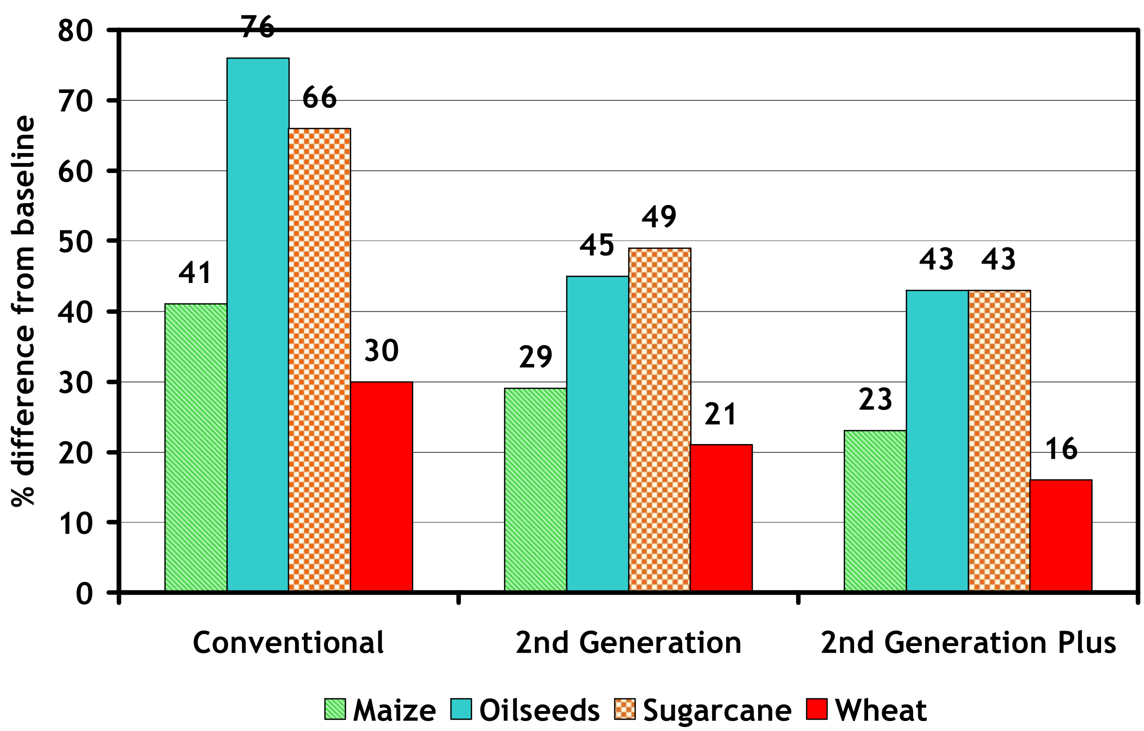
Source: Author calculations.

Figure 5: Yield Enhancements over Baseline for "Plus" Scenario



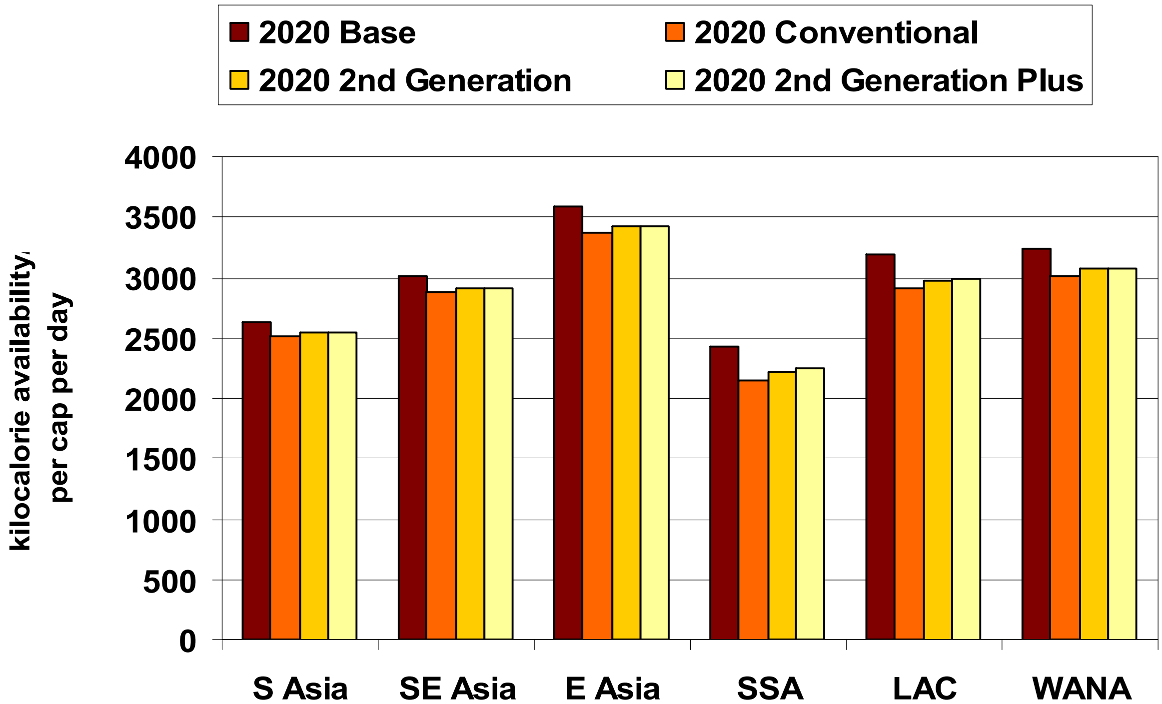
Source: IMPACT simulations (October 2006).

Figure 6: Changes in Global Commodity Prices from Baseline Across Scenarios in 2020



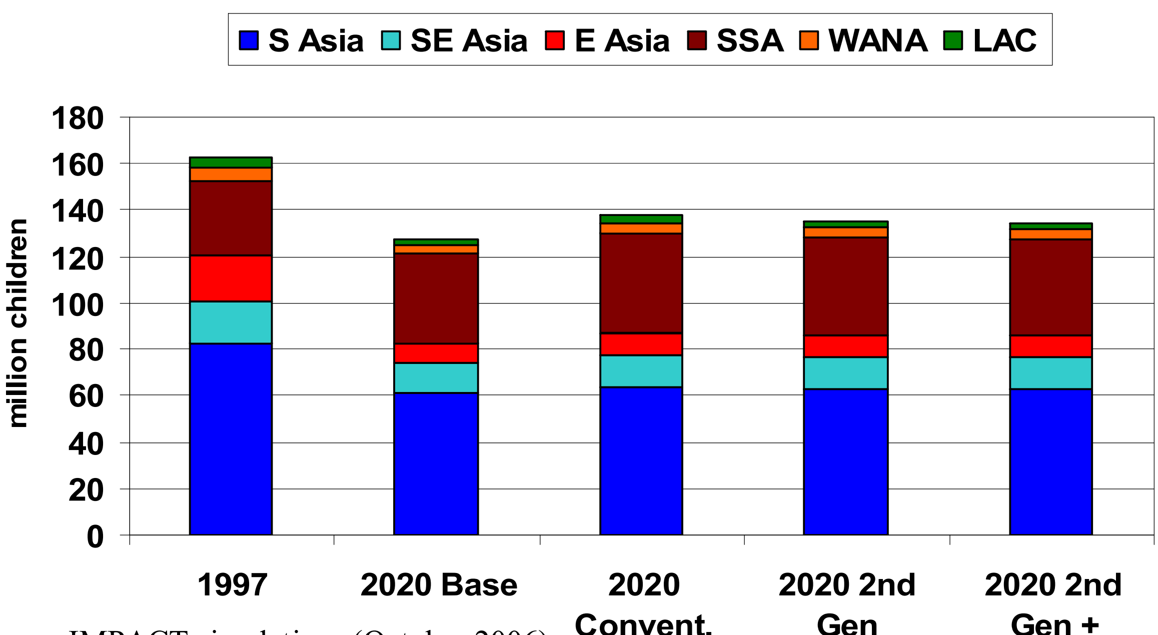
Source: IMPACT simulations (October 2006).

Figure 7: Calorie Availability Per Capita Per Day Across Scenarios, 2020



Source: IMPACT simulations (October 2006).

Figure 8: Changes in Childhood Malnutrition, 1997 and Projections to 2020, Alternative Scenarios



Source: IMPACT simulations (October 2006).

Table 1. Types of biomass resources and biofuel produced.

Biomass Resources	Biofuel produced	Energy services
Agriculture and forestry residues	Wood pellets, briquettes, biodiesel	Heat, electricity, transport
Energy crops: biomass, sugar, oil	Char/charcoal, fuel gas, bio-oil; bioethanol	Heat, electricity, transport
Biomass processing wastes	Biogas, bioethanol, solvents	Transport
Municipal waste	Refuse-derived fuel, biogas	Heat, electricity

Source: Adapted from IEA Bioenergy 2005

Table 2: Global Production of BioEthanol

Country/ Region	Ethanol Production (million liters)	Share of Total Ethanol Production (percent)
Brazil	16,500	45.2
United States	16,230	44.5
China	2,000	5.5
European Union	950	2.6
India	300	0.8
Canada	250	0.7
Colombia	150	0.4
Thailand	60	0.2
Australia	60	0.2
World Total	36,500	100.0

Source: F.O. Licht (2005)

Table 3: Global Production of BioDiesel

Country/ Region	Biodiesel Production (million liters)	Share of Total Ethanol Production (percent)
Germany	1,921	54.5
France	511	14.5
Italy, Austria, Denmark, United Kingdom, Czech Republic, Poland, Spain, Sweden	9 - 227	0.1 – 6.4
Europe Total	3,121	88.6
United States	290	8.2
Other	114	3.2
World Total	3,524	100.0

Source: F.O. Licht (2005)